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Polymer Composite Reliability Requirements for Large Space Structures

Abstract

Long-life (10-30 years) large space structures are considered by NASA for a number of future earth-orbiting missions. The use of very thin graphite-fiber composites have been considered as structural materials for the fabrication of these structures. A combination of analytical and experimental approaches will be needed to provide a reliable data base on engineering properties of these materials to be used in the design and fabrication of these structures, which will be able to withstand the space environment.

Keywords

Nondestructive Evaluation

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POLYMER COMPOSITE RELIABILITY REQUIREMENTS FOR LARGE SPACE STRUCTURES

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ABSTRACT

Long-life (10-30 years) large space structures are considered by NASA for a number of future earth-orbiting missions. The use of very thin graphite-fiber composites have been considered as structural materials for the fabrication of these structures. A combination of analytical and experimental approaches will be needed to provide a reliable data base on engineering properties of these materials to be used in the design and fabrication of these structures, which will be able to withstand the space environment.

Studies of planned NASA missions indicate that multiuser, multipurpose science and application platforms can achieve cost efficiencies and enhanced reliability through shared support systems, shared operations, and on-orbit serving using the operational Space Shuttle. These multiuser platforms will evolve in succeeding years into highly complex platforms for communications of scientific observations capable of greatly increasing spacecraft efficiency and utilization (Fig. 1). Technical considerations and economics require these structures to be designed for space operational loads and for long life (10 to 30 years).

The technological issues for these new structures may be exemplified by current activities on the development of precision deployable antennas (Ref. 1) for applications such as large earth viewing radiometers. This concept is intended for antennas from 30 to several hundred meters in diameter and for operation at 100 GHz and above. The deployable reflector structure requires high surface precision (Fig. 2). Pulsed laser ranging systems (Fig. 3) are being evaluated for measuring and controlling the surface curvature (Ref. 2).

In order to meet the requirements for lightweight and adequate strength, very thin (1.0 mm or less) graphite fiber composites are being considered as primary structural materials. Both epoxy and polyimide based composites are being investigated. The possibility of using polysulfone (a thermoplastic) based composites is being considered for its potential for fabrication in space using techniques such as pulltrusion. For large structures, technology applications long-term dimensional integrity along with minimal tendency for thermal distortion are essential.

One of the major uncertainties in the use of composites is the effect of space radiation on mechanical and physical properties. The effects of high energy electrons and protons (and to a lesser extent other high energy particles) must be considered. Although their penetration depth is rather low, the effects will be significant considering the thinness of the composites to be used. The nature and the extent of degradation will depend on the radiation profile in a particular orbit (e.g., geosynchronous) and on the chemical nature of the composites (e.g., epoxy or polyimide/graphite).

The complexity of the long-term effects of the space environment and the lack of an applicable data base dictate the development of a combined analytical and accelerated experimental program to realistically predict temporal energy degradation profiles in materials of interest. Analyses of the relative complexities and costs of the various test program options show that for a cost and time effective approach one cannot simulate the space environment in detail, but that one must reproduce material degradation profiles by a judicious combination (some simultaneous and some sequential) of radiation/temperature/time (Ref. 3).

Experimental techniques which are being developed at JPL rely to a large extent on transient measurements in order to identify primary effects of radiation on materials. For an assessment of UV induced degradation mechanisms flash photolysis is being used (Fig. 4). Similarly, pulsed e-beam sources are being used to study high energy electron mechanisms (Ref. 4). These experimental data are used then along with other conventional measurements for determining radiation effects to develop analytical models for predicting long-term effects in space.

Material defects which ultimately may compromise the performance of a structure may have their origin beginning with the selection of materials prior to fabrication and all the way to the final operational environment (Fig. 5). The previously proposed reliability concepts (Ref. 5) are applicable provided that preventive NDE is used extensively to assure that components such as prepreps and adhesively bonded structures are cured to final states which were qualified by extensive tests and analyses of the long-term effects of space radiation. For the duration of a mission NDE will be required for inspection and for repair/replace decisions.

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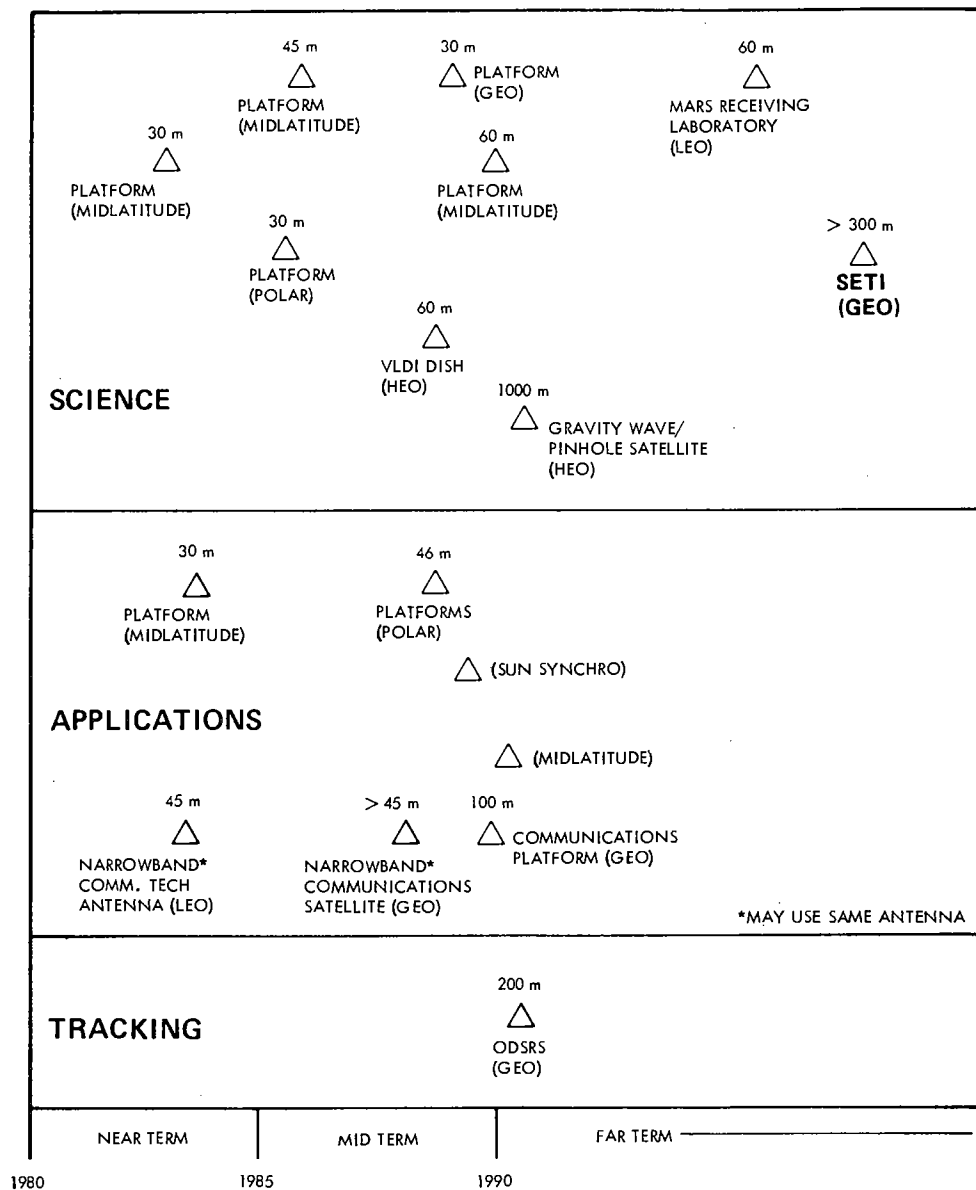


Fig. 1. NASA OAST Missions Involving Large Space Systems (Ref. 1).

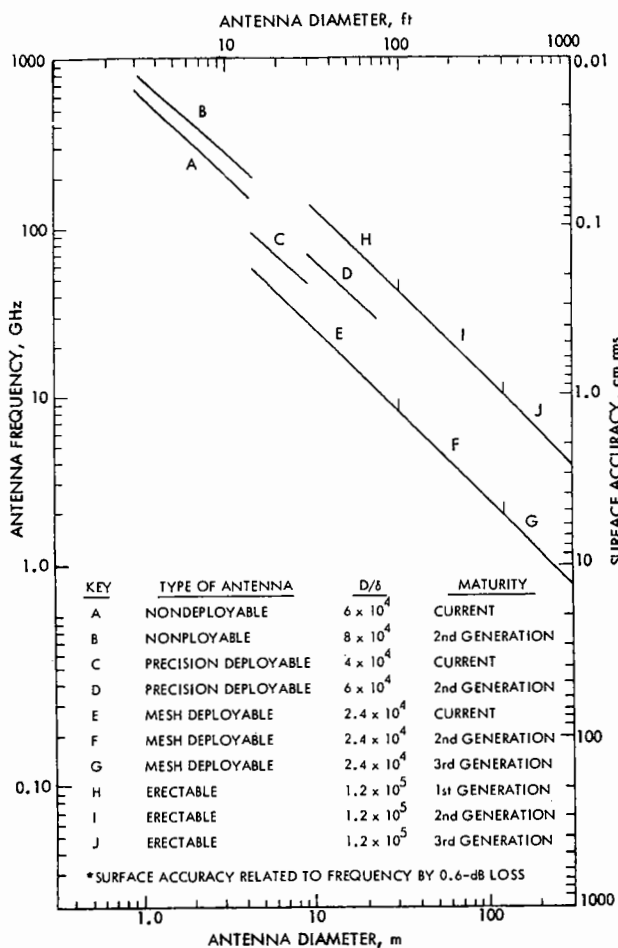


Fig. 2. Surface Precision Requirements for Deployable Antennas.

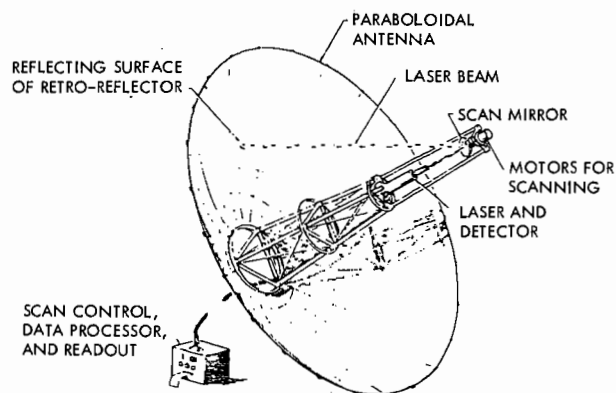


Fig. 3. Antenna Surface Measuring System (Ref. 2)

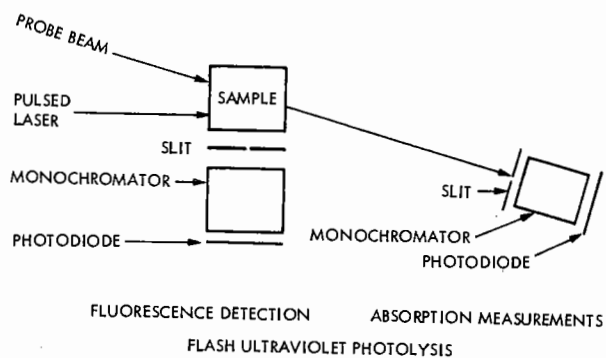


Fig. 4. Flash Photokinetic Spectroscopy Utilizing A Pulsed Laser in the Ultraviolet; Time Resolution of Such Systems Can Be 1 ns.

A. CHEMICAL STRUCTURE DEFECTS	B. MANUFACTURING DEFECTS	C. MACROSCOPIC FATIGUE DEFECTS
<ul style="list-style-type: none"> • 10-200 Å IN SIZE • CONTROL CRITICAL DESIGN PROPERTIES (T_g, MOISTURE ABSORPTION, DIMENSIONAL STABILITY) • CONTROLLED BY <ul style="list-style-type: none"> • CHEMICAL ANALYSIS • SELECTION OF MATERIAL 	<ul style="list-style-type: none"> • $>10 \mu\text{m}$ IN SIZE (INCLUSIONS, VOIDS, DEBONDS) • RESULTS FROM NON-OPTIMUM PROCESS AND QUALITY CONTROL • DETECTED BY <ul style="list-style-type: none"> • ULTRASONICS • OPTICAL SCANNING • TECHNIQUES SENSITIVE TO INTERFACIAL IMPERFECTIONS 	<ul style="list-style-type: none"> • RESULTS FROM THE INTERACTION OF (A) AND (B) WITH MECHANICAL AND ENVIRONMENTAL STRESSES • NETWORK OF MICROCRACKS • SINGULAR MICROSCOPIC CRACK GROWTH • DETECTED BY <ul style="list-style-type: none"> • ULTRASONIC EMISSION • MOISTURE DIFFUSION ANALYSIS • OPTICAL INSPECTION

Fig. 5. Origins of Material Defects.

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